Proceedings of the Institute of Acoustics

PREDICTION SCHEMES FOR OUTDOOR NOISE

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1. INTRODUCTION

Noise from industrial plants and various other sources in residential areas can cause disturbance and annoyance. Environmental protection authorities in many countries have issued laws, regulations and guidance for the setting of noise limits and controlling modes of operation of the offending plant. An important task in this context is to develop an accurate method for predicting noise levels. The purposes of noise prediction schemes are

(1) to provide a scientific basis for planning new industrial areas, zoning and setting realistic noise limits, and

(2) to provide information concerning sound radiation from plant for the use of managers and engineers in choosing low-noise equipment, sound-reducing structures, determining noise reducing layouts for the plant buildings and industrial sites, and finding the most cost-effective noise reduction measures for their installations.

Prediction of noise may be useful also during assessment of potential noise nuisance when the background noise prevents reliable measurements at potentially sensitive locations.

Noise from industrial plant will be subject to wave front spreading, atmospheric absorption, loss and enhancement due to presence of the ground *(ground effect)*, attenuation effects due to presence of trees, attenuation or enhancement due to sound velocity profiles induced by wind shear and temperature gradients, increased temporal variability as a result of turbulence and topographical and barrier effects which may include in-plant screening. Several prediction schemes take many of these propagation factors into account (1-4).

A comparison of measured and predicted levels around several refineries found that the majority of predictions by the CONCAWE scheme were within 5 dB(A) of the median value (L_{50}) of noise measurements made over a month or more (1).

There was a tendency for the predictions to be higher than the measurements. Particularly large confidence limits were found in the 250 Hz, 500 Hz and 2 kHz bands. In the Nordic schemes, observations of received levels both higher and lower than those predicted have been reported (2, 3).

In the CONCAWE scheme the influence of the ground is calculated according to an empirical formula based upon measurements of propagation from a fixed height jet engine at two airfields. The resulting ground effect correction depends only upon distance and isconcrete or water a correction of - 3 dB independent of frequency is advocated. For all independent of the height of the propagation path. For acoustically hard surfaces such as other surfaces the recommended ground effect occurs in the 250 Hz and 500 Hz bands. In the Nordic and ISO schemes, while again distinction is drawn between hard and soft ground, the ground effect corrections depend upon source and receiver heights as well as the horizontal separation. The recommended ISO procedure (4) involves the additional complication of distinction between the ground types in the different regions around the source, the receiver and between the source and the receiver. This is suggested as a consequence of steady downward refraction which produces curved propagation paths and emphasizes the importance of the ground characteristics near source and receiver. In the ISO scheme soft or absorbing ground is said to include '*ground covered by grass, woods or other vegetation, and all other porous grounds suitable for vegetation, such as farming land.*

Inadequate correction for ground effect has been suggested in several cases where there has been a substantial discrepancy between measurement and prediction (1, 4). Indeed it is remarked in the Nordic schemes that, like in the CONCAWE scheme, the recommended ground effect corrections for soft ground are based almost entirely on measurements made over grassland. It is further remarked that extension to other types of surfaces is not possible without extensive field investigations.

In the CONCAWE scheme it is stated that, although vegetation and trees will play a part in outdoor sound attenuation, the wide discrepancy observed in the data available in relevant studies at that time (1982) resulted in no correction being recommended. On the other hand the Nordic schemes and the ISO scheme suggest a frequency dependent correction per tree belt, independent of belt width traversed by the assumed (curved) propagation path, plus an additional, mainly high frequency, correction per metre length of the path through foliage.

In this paper we review and describe the results of recent theoretical and experimental work on ground effect, particularly over cultivated ground and snow, and on attenuation through trees, and assess its implications for the validity of the prediction schemes currently available.

2. GROUND EFFECT

When sound is reflected at the ground surface it suffers a phase change the magnitude of which dependent upon the porosity and air permeability of the ground surface. Where the ground is porous and the source is an elevated point source there will be a frequency band in which this phase change, when added to that due to the path length difference between direct and ground reflected sound, is close to 180°, producing destructive interference and consequent attenuation of sound propagation close to the ground surface. A spectrum of the attenuation in excess of that due to wave front spreading alone exhibits the characteristic ground effect maximum. At frequencies below this band the attenuation is near zero or negative. Negative attenuation is a consequence of ground and surface waves. Negative excess attenuations less than -6 dB are possible and are a consequence of surface waves. Ground and surface waves are the only modes of propagation from a point source on the ground to a receiver also on the ground. The ground and surface wave contributions are particularly evident above ground where there is near surface layering. At frequencies higher than the main ground effect maximum (corresponding to a dip in the received spectrum level), ground interference effects will extend as far as coherence between direct and ground-reflected sound is maintained. In practice this is reduced over level ground by turbulence.

For a given elevated source-receiver geometry, then the more porous and permeable the ground surface, the lower the frequency band in which the ground effect dip in the received spectrum will be. This is illustrated by the classical measurement data shown in Figure 1, where the attenuation due to the snow cover represented by asterisks clearly exceeds and takes place at lower frequencies than those over the airfield grass (open squares and triangles) without snow cover. Note that in Figure 1 attenuation increases downwards. Methods of predicting the excess attenuation over ground surfaces in terms of the source-receiver geometry and the surface normal impedance of the ground are well established and are explained in detail elsewhere (5). Use of the Weyl van der Pol formula (5) has been shown to give a close approximation to the results of numerical integration for a relevant range of surface impedances (6). Typically two and three parameter models based on a microstructural consideration of the acoustical properties of granular materials permit prediction of the normal surface impedance in terms of physical properties (5, 7) and a classification of the vertical inhomogeneity.

Many cultivated grounds and thick snow in which the upper few centimetres are homogeneous, may be described in terms of three parameters; effective flow resistivity, porosity and tortuosity. Broadly speaking the lower the flow resistivity, the higher the porosity and for a given geometry the lower the frequency band in which there is significant excess attenuation. Tortuosity tends to influence only the high frequency impedance. However the magnitude of the ground effect attenuation maximum depends also on the variation of the ground properties with depth (5, 7, 8). Near-surface layering, below a permeable and highly porous upper layer, tends to produce a much larger ground effect maximum (5).

As a consequence of the accuracy of predictions using the Weyl van der Pol formula that has been observed out to ranges in excess of 300 m in neutral propagation conditions several authors have advocated use of ground characterisation by means of short range measurements (9, 10). It is proposed that such short range characterisation may be used (5) to predict excess attenuation at longer ranges. Table 1 shows a set of best fit parameters and average values that characterise the acoustical properties of cultivated soils and which have been obtained from short range propagation measurements (8). The measurements were made with a point noise source, comprising a small loudspeaker driver unit on to which was screwed a cylindrical tube, and a pair of vertically separated microphones typically at heights of 0.5 m and 0.1 m and at a horizontal range of 1.5 m from the source.

It has been found possible to describe normal surface impedance data on snow, obtained by means of a standing wave apparatus, in terms of the three parameters of effective flow resistivity, porosity and tortuosity (11). From these data, a range of parameter values and associated averages may be deduced as shown in Table 1 also.

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TABLE 1. Best fit ground parameters for various soils.

Parameter values obtained by best-fit to acoustic data (8, 11)	Effective flow resistivity	Tortuosity	Porosity
Sandy Loam dry	24050	3.32	0.52
Sandy Loam moist	9380	1.23	0.39
Clay Day 1 wheeled	14085	3.87	0.53
Clay Day 1 unwheeled	12070	1.94	0.57
Clay Day 2 wheeled	3680	2.68	0.42
Clay Day 2 unwheeled	6280	3.35	0.57
Silt A day 1 cultivated	8670	2.89	0.56
Silt A day 2 cultivated	6040	2.24	0.49
Silt A Day 2 compacted	14260	2.41	0.18
Approximate averages (farmland)	22000	2.7	0.47
Snow (range of best fit values)	680-2500	1.14-1.76	0.57-0.86
Approximate averages (snow)	2900	1.5	0.7

Table 2 shows the results of using the averaged parameters for farmland and snow in the point source propagation theory and compares these results with those obtained from the ISO scheme (4) for three different source-receiver geometries. Where there are significant differences the ISO values are underlined. The most striking indication is that the ISO scheme considerably underestimates the excess attenuation for geometry 2 (source height 1.5 m, receiver height 1.5 m, horizontal separation 250 m). This underestimation will be increased at longer ranges. A systematic indication is that the ISO scheme overestimates the frequency of maximum excess attenuation for propagation over cultivated soil or snow based as it is predominantly on grassland data.

Typically grassland will have higher flow resistivities and lower porosities than cultivated soil or snow. The rather low flow resistivities of snow result in highest attenuation in the lowest octave bands. This difference will be exaggerated by downward refraction.

TABLE 2 Predicted octave-band excess attenuations over farmland and snow compared with ISO WG 24 predictions for porous ground.

Octave band	Geometry 1			Geometry 2			Geometry 3		
centre frequency	ISO	Farmland	Snow	ISO	Farmland	Snow	ISO	Farmland	Snow
31.5	–	–3.5	0.5	–	–2.5	2.5	–	–1.4	3.5
63	–3	–3	6.5	–5	5.5	11	–2	5	9.5
125	1.5	11	11.5	3	19	18	1.5	9.5	10
250	12	13	11.5	14	22	18.5	7	7.5	5.5
500	8.5	10	7.5	10	16	14.5	5	1.5	0
1000	1	2	2.5	1	10	10	0.5	–3	–4
2000	0	–2.5	–2.5	0	4	4	0	–3	–4.5

Geometry 1: – Source height 1.5 m, Reciever height 1.5 m, range 100 m

Geometry 2: – Source height 1.5m, Reciever height 1.5 m, range 250 m

Geometry 3: – Source height 10 m, Receiver height 1.5 m, range 250 m

3. SOUND ATTENUATION THROUGH TREES

The frequency dependence of the time-averaged attenuation of sound propagating through up to 100 m of dense woodland has been shown to have a characteristic form (12, 13). The data were collected on dry, windless days and show close repeatability both from time to time during any one day and from day to day separated by up to one month. Indeed a study of propagation through a pine forest in a variety of well documented weather conditions (13) has shown a striking invariance of the attenuation at 100 m range. Non-averaged sound transmission measurements demonstrate that rapidly varying temperature effects do occur, but these disappear in the averaging process. A close examination of the data collected above 1 kHz in three British woodlands and in a Dutch pine forest shows a consistent tendency for the attenuation to increase with frequency. Figure 2 shows that the dense mixed coniferous woodland (curve a) offers greater high-frequency attenuation than either a spruce monoculture (curve b) or a mixed deciduous woodland in summer (curve c). The mixed deciduous woodland offers least mean attenuation of all in the winter (without foliage - curve d). The curves are based upon measurements made at several different ranges (between 24 m and 96 m) but reduced to a common standard of attenuation in dB per 24 m.

The measured attenuation spectra may be modelled by a combination of ground attenuation and multiple scattering by two distinct arrays of large and small vertical cylinders representing the tree trunks and the foliage respectively (12). The ground effect for all three woodlands corresponds to rather low effective flow resistivities than those appropriate to grassland. Although woodland offers a range of tree trunk diameters, calculations show that the assumption of a single mean diameter, an appropriate areal density and rigid cylinders, is tolerable for the prediction. The additional array of small scatterers either acoustically-hard or soft is included for best fit, since foliage is not amenable to representation by regular geometries.

Kragh et al (12) have described a scheme that accounts for attenuation of sound by woodland including the contribution from the acoustically-soft ground. A similar scheme has been proposed by an ISO working group (4). These schemes allow for a 'soft' ground effect plus a high-frequency attenuation, increasing with frequency and expressed in dB per metre path length. The results of these schemes may be compared with a semi-empirical model based on the studies and data previously described (12). Such a comparison is made in Figure 3 for 100 m horizontal propagation path with both source and receiver 1.2m above ground. The comparison indicates that the prediction schemes may give considerable underestimation of attenuation particularly at high frequencies. The semi-empirical model assumes an effective flow resistivity for the ground of 34000 mks units and distinguishes between three different vegetation density ranges; open, intermediate and dense. The break in the predicted curves corresponds to an arbitrarily-chosen switch from ground effect to attenuation by trunk and foliage scattering. This can be avoided by including an empirically-calculated coherence-degradation term into the calculation (14).

4 CONCLUSIONS

While the basic form of frequency-dependent and geometry-dependent ground effect correction suggested in the more sophisticated schemes for predicting noise levels around fixed industrial premises is correct, it has been argued in this paper that the actual correction for propagation at appreciable ranges over soft ground will lead to considerable underestimation of attenuation where the ground surface is cultivated or thickly snow-covered. The latter situation will only be relevant to locations in more severe climates than that in the UK. However, propagation over farmland is not uncommon and the finding in this paper, coupled with other evidence for the variety of acoustical characteristics of ground surfaces (5, 7 - 9), suggests that a more refined ground effect calculation, allowing for a larger number of ground state categories, would lead to significant improvements in predictions.

Improved understanding of ground effect means that, not only may it be taken into account in prediction schemes, but it may be exploited as a noise reducing measure in its own right. Recent work has indicated the possibilities for assessing the maximum ground effect attenuation from a broad band source and for a given geometry, and for specifying a ground surface that will achieve this maximum (15).

Recently proposed prediction scheme corrections for attenuation by trees have been shown both experimentally and theoretically to be in error. Partly this is the result of inadequate ground effect allowance, and partly it is a result of underestimation of the effects of trunks and foliage.

5. REFERENCES

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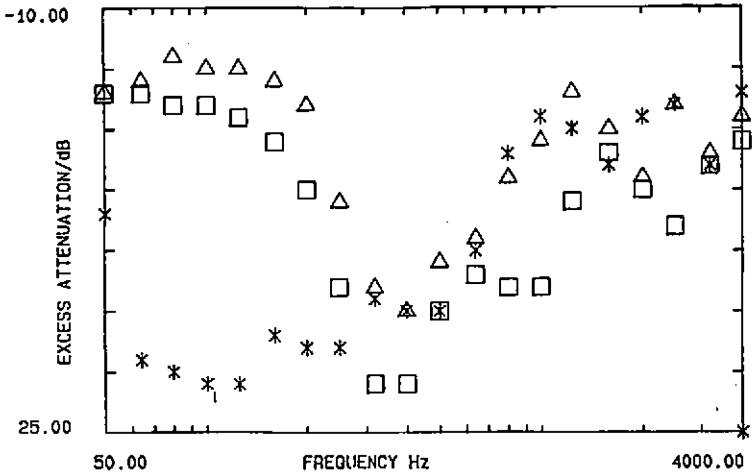

Fig. 1. Data for the difference in levels received at 19 M and 347 M from a fixed jet engine source, corrected for spherical spreading over airfields at Radlett (open squares) and at Hatfield with (asterisks) and without (open triangles) 0.2 M of snow cover (see ref. (5)).

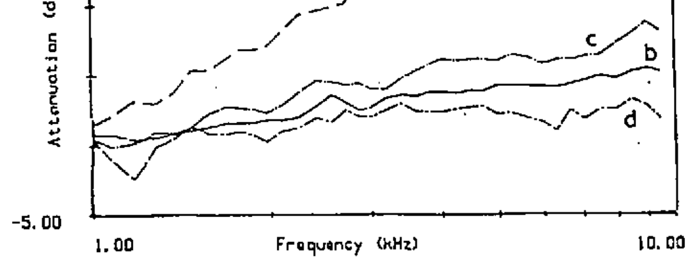

Fig.2. Mean measured attenuation (dB per 24 M) above l kHz woodland sites; (a) mixed coniferous, (b) Norway spruce monoculture, (c) mixed deciduous in summer and (d) in winter.

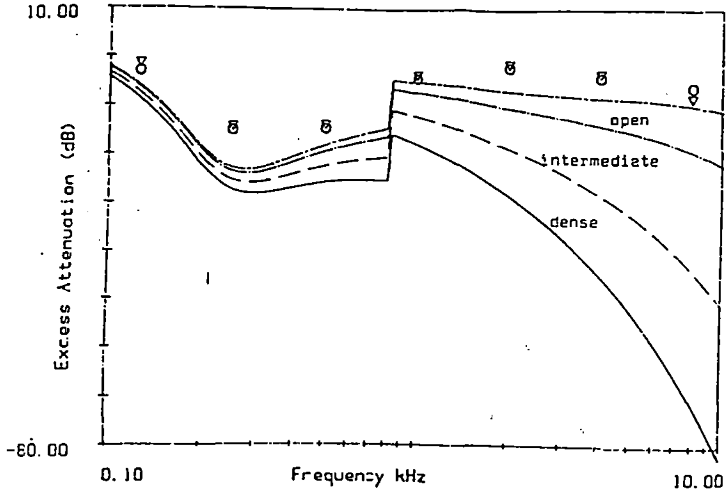

Fig.3. Predicted ranges of excess attenuation over 100 M at a propagation path height of 1.2 M through woodland of different densities compared with the corresponding corrections suggested in the ISO scheme (4).